WPS5618

Policy Research Working Paper 5618

Water and Sanitation to Reduce Child Mortality

The Impact and Cost of Water and Sanitation Infrastructure

Isabel Günther
Günther Fink

The World Bank
Development Economics
Prospects Group
March 2011

Policy Research Working Paper 5618

Abstract

Using household survey data, this paper estimates the mortality impact of improved water and sanitation access in order to evaluate the potential contribution of water and sanitation investment toward achieving the child mortality targets defined in Millennium Development Goal 4. The authors find that the average mortality reduction achievable by investment in water and sanitation infrastructure is 25 deaths per 1,000 children born across countries, a difference that accounts for about 40 percent of the gap between current child mortality rates and the 2015 target set in the Millennium Development Goals. According to the estimates, full household coverage with water and sanitation infrastructure could lead to a total reduction of 2.2 million child deaths per year in the developing world. Combining this analysis with cost data for water and sanitation infrastructure, the authors estimate that the average cost per life-year saved ranges between 65 and 80 percent of developing countries' annual gross domestic product per capita. The results suggest that investment in water and sanitation is a highly cost-effective policy option, even when only the mortality benefits are taken into consideration. Taking into account the additional expected benefits, such as reduced morbidity, time spending, and environmental hazards, would further increase the benefit-cost ratio.

This paper is a product of the rospects Group, Development Economics. It is part of a larger effort by the World Bank to provide open access to its research and make a contribution to development policy discussions around the world. Policy Research Working Papers are also posted on the Web at http://econ.worldbank.org. The author may be contacted at isabel.guenther@nadel.ethz.ch.

Water and Sanitation to Reduce Child Mortality

The Impact and Cost of Water and Sanitation Infrastructure

Isabel Günther and Günther Fink[1]

[1] Isabel Günther (the corresponding author): Center for Development and Cooperation (NADEL). ETH Zürich. E-mail: isabel.guenther@nadel.ethz.ch; Günther Fink: Harvard School of Public Health. E-mail: gfink@hsph.harvard.edu.
The authors thank two anonymous referees for very valuable comments on a previous version of the paper and the World Banks Knowledge for Change Program for funding this research. The views and findings in this paper are those of the authors and not necessarily those of the World Bank, its Executive Board, or member country governments.

1. Introduction

Following the United Nations Millennium Summit in New York City in 2000, eight Millennium Development Goals (MDGs) were established as clearly defined and measurable country-specific development objectives for the following 15 years. Ten years later, substantial progress has been made in some areas, while relatively little has been achieved in others. At the regional level, Sub-Saharan Africa remains – despite significant progress in some countries - the region lagging most behind the 2015 targets, in particular when it comes to reducing child mortality (MDG 4), and reducing the population without access to improved water and sanitation (MDG 7).

According to the latest Millennium Development Goals Report (UN, 2009), *"for the developing regions as a whole, the under-five mortality rate dropped from 103 in 1990 to 74 in 2007. Still, many countries, particularly in Sub-Saharan Africa, have made little or no progress at all. Together with high levels of fertility, this has resulted in an increase in the absolute number of under-five deaths from 4.2 million in 1990 to 4.6 million in 2007.*" The results look similarly bleak for water and sanitation. According to the latest available estimates, 42% of households in Sub-Saharan Africa remain without access to safe drinking water, and 64% of households remain without access to basic sanitation (WHO/UNICEF, 2004), leading the MDG report to conclude that "…*rapid acceleration of progress is needed to bring improved sanitation. At the present rate of progress the 2015 sanitation target will be missed"* (UN, 2009).

The slow progress made in providing households with adequate water and sanitation infrastructure is disconcerting from a global health perspective. Estimates on the combined health effects of improved water and sanitation are large, with an estimated reduction of 20 to 40 percent of diarrhea prevalence with access to both improved water and sanitation (see e.g. Esrey et al., 1991; Esrey, 1996; Cairncross and Kolsky, 1997; Fewtrell et al., 2005; Waddington et al., 2009; Günther and Fink, 2010). Given that diarrheal diseases alone are responsible for approximately 1.7 million deaths of children under the age of five per year – a death toll exceeding the combined under-5 mortality burden attributed to Malaria and HIV (WHO, 2008) – the potential reductions in child mortality achievable through water and sanitation investment appear large.

Even though it seems obvious that unsafe water and poor sanitation increase both morbiditiy and mortality associated with waterborne diseases, relatively few studies have directly focused on child mortality as a primary outcome of interest. Those that have analyzed the impact of water and sanitation infrastructure on child mortality generally combine national burden of disease accounts with epidemiological estimates of the impact of water and sanitation on morbidity to compute (disability-adjusted) life-years lost due to inappropriate water and sanitation infrastructure (Clasen et al., 2007; Pruess et al., 2002; Pruess-Uestuen et al., 2008). In the most recent study in this area, Pruess-Uestuen and coauthors (2008) estimate that about 3.5 million (child and adult) deaths could be prevented worldwide per year with investments in water, sanitation and hygiene. The studies that have undertaken cost-benefit analyses of improved water and sanitation infrastructure[2] have mostly focused on the benefits from avoided illness cost (and time savings), and only took these indirect estimates of deaths prevented into account (e.g. Hutton and Haller, 2004; Hutton, Haller, and Bartram, 2007; Rijsberman and Zwane, 2008; Whittington et. al, 2008).[3]

While diarrhea-focused studies allow some inference about the mortality effects of water and sanitation, the derived links are indirect, and unlikely to reveal the full mortality benefits of water and sanitation infrastructure investment. An extensive literature suggests that the effects of improved water and sanitation on child mortality go beyond their direct diarrheal effect. By lowering the exposure to fecally-transmitted diseases, access to improved water and sanitation does not only lower diarrhea incidence but also considerably lowers the risk of malnutrition (Pruess-Uestuen et al., 2008) as well as the risk of severe infection with other (not fecally-transmitted) diseases, enhancing the chances of survival for protected children (Caulfield et al, 2004; Cutler and Miller, 2005; Ewbank and Preston, 1990; Walker et al, 2007).

In this paper we focus on child mortality as one of the primary policy objectives within the MDG framework. Given that Sub-Saharan Africa has been lagging behind both with respect to the mortality (MDG 4) and the water and sanitation objectives (MDG 7), we try to answer three simple, but highly policy-relevant questions: First, what is the reduction in under-5 mortality that countries could achieve if all households in a country had access to improved water and sanitation? Second, how much could improved water and sanitation infrastructure contribute to close the gap between the status quo of child mortality and the MDG 4 target?

[2] Mostly commissioned by the World Health Organization and the Copenhagen Consensus.
[3] In these studies, the return to 1 US$ invested in water and sanitation infrastructure was estimated to be between 5 US$ and 30 US$, with substantial variation in the returns across countries.

And last, how much would such an intervention cost in terms of dollars per life-year saved and what does this imply in terms of cost-effectiveness?[4]

To answer these questions, we analyze 38 developing countries where recent Demographic and Health Surveys (DHS) are available. Building on a previous paper (Günther and Fink, 2010) we first estimate a logistic model to quantify the effect of improved water and sanitation on child mortality. Based on the estimated relation between water, sanitation and child mortality, we compute counterfactual child mortality rates under various water and sanitation improvement scenarios in a second step. In a third step, we compare the predicted mortality changes to the country-specific child mortality goals set in MDG 4. In a last step, we price the infrastructure investment needed for each of the relevant scenarios, and calculate country-specific estimates of cost per life-year saved.

Our empirical estimates suggest that, on average, access to "basic" improved water and sanitation technology (such as public water pumps and ventilated improved pit latrines) lowers child mortality by 8 deaths per 1000 children born, while high-end technologies as private water connections and flush toilets lead to an average mortality reduction of 25 deaths per 1000 live births.[5] Compared to the current gap between child mortality and the 2015 mortality targets this implies that basic improved water and sanitation could on average reduce the gap by about 13 percent, while private piped water and flush toilets would reduce the mortality gap by about 41 percent. Given the high degree of heterogeneity across countries in terms of current infrastructure and child mortality, the variations in the potential progress towards achieving MDG 4 are substantial across regions and countries.

Our calculations show that the cost associated with water and infrastructure improvements is substantial in absolute terms, but not necessarily large when compared to the number of life-years saved. Across all Sub-Saharan African countries, we estimate the average cost per life-year saved at around US$ 1000, with similar estimates for basic technologies and household water connections and flush toilets. Even though piped water and connected toilets are much more expensive than low-tech technologies, the average cost per life-year saved turns out to be roughly the same due to the longer durability and superior health impact associated with the higher-end technologies.

[4] In this study we only analyze the total mortality effect of improved water and sanitation infrastructure, but exclude morbidity and nutrition effects that might have long-term consequences for schooling outcomes, labor-force productivity and hence lifetime earnings. Our cost benefit analysis therefore only takes into account life-years saved, following a pure health perspective.

[5] For a detailed definition of improved water and sanitation technology see Table 2.

Outside of Sub-Saharan Africa, mortality rates are already lower and existing infrastructure coverage is higher, which results in a higher expected cost of around US$ 3000 per life-year saved. However, given the higher average income levels in these developing countries, the ratio of the cost per life-year saved relative to income per capita is similar, and ranges between 0.65 and 0.82 across regions. Given that the WHO guidelines classify any intervention costing less than the annual GDP per capita per life-year saved as “highly cost effective”[6], further investment in water and sanitation appears highly desirable from a policy perspective.

The estimates presented in this paper also underline the magnitude of the potential humanitarian impact of further investments in water and sanitation. Our estimates imply that in our sample alone – which accounts for approximately 60% of the 102.5 million children born per year in the developing world[7] (World Population Prospects, United Nations Population Division) - providing full access to water and sanitation infrastructure to all children has the potential to save about 1.3 million child lives per year. Assuming comparable health improvements in the rest of the developing world, this means that approximately 2.2 million lives could be saved across all developing countries each year if access to the first-best water and sanitation infrastructure could be provided to all households in the developing world.

The rest of this paper is structured as follows: in Section 2 and 3, we discuss the data and methodology used, providing a detailed description of the construction of the main variables of interest. We present the estimation results in Section 4, and compare the predicted reductions in child mortality rates with the current gap between child mortality and the MDG objective for each country. We also show estimates of total investment needed per life-year saved. We conclude with a discussion of our estimates in relation to the existing literature and a short summary in Section 5.

[6] www.who.int/choice/costs/CER_thresholds/en/index.html
[7] Excluding China.

2. Data

The data we use are from the Demographic and Health Surveys (DHS). The DHS are nationally representative household surveys that have been conducted in more than 70 low- and middle-income countries since 1985. Most countries have multiple survey rounds, with an average spacing of about 5 years between surveys. Calculating the maximum absolute child mortality reduction achievable with investments in water and sanitation infrastructure requires recent estimates of water and sanitation coverage and child mortality rates. Since it does not appear plausible to assess current infrastructure gaps and investment needs based on data from the 1980s and 1990s, we exclude surveys prior to the year 2000. In countries where two surveys are available after 2000, we use the most recent survey. As summarized in Table 1, this leaves us with 38 surveys collected between 2000 and 2006, a sample more up-to-date but also smaller than the full DHS sample analyzed in the preceding paper in this series (Günther and Fink, 2010).

Table 1: Survey List

#	Country	Year	#	Country	Year	#	Country	Year
1	Azerbaijan	2006	14	Haiti	2005	27	Nicaragua	2001
2	Bangladesh	2004	15	India	2005	28	Niger	2006
3	Benin	2006	16	Indonesia	2002	29	Nigeria	2003
4	Bolivia	2003	17	Kenya	2003	30	Pakistan	2006
5	Burkina	2003	18	Lesotho	2004	31	Peru	2003
6	Cambodia	2000	29	Liberia	2006	32	Philippines	2003
7	Cameroon	2004	20	Madagasc	2003	33	Senegal	2005
8	Chad	2004	21	Malawi	2004	34	Swaziland	2006
9	Congo,	2005	22	Mali	2006	35	Tanzania	2004
10	Dominican	2002	23	Morocco	2003	36	Uganda	2006
11	Gabon	2000	24	Mozambi	2003	37	Zambia	2001
12	Ghana	2003	25	Namibia	2006	38	Zimbabwe	2005
13	Guinea	2005	26	Nepal	2006			

Out of the 38 countries in this simple, 25 are located in Sub-Saharan Africa; the rest of the sample is fairly evenly distributed across South- and South-East Asia as well as Central and South America.

Child mortality as the primary outcome variable of interest in this paper is generally defined as the number of children dying before the age of five per 1000 children born alive. This number can either be computed as a cohort measure, which means that a given birth cohort is followed over a five year period, or as a period measure, in which age-specific mortality rates from different birth cohorts are combined for a given time window. Even though cohort measures may seem more intuitive, they are problematic from an analytical perspective, since the estimated mortality rates reflect risk exposure over an extended period of time with potentially large changes in the underlying risk structure.

To minimize the time difference between observed water and sanitation infrastructure and mortality outcomes, we limit our analysis to mortality within the 12-months-window preceding the household interview. The dependent variable we construct is a binary variable capturing the probability of a child between the age of 0 and 48 months dying over the 12 months interval leading up to the interview. This mortality variable thus excludes children who died more than 12 months before the respective DHS survey, children older than 48 months one year prior to the interview, and children born less than 12 months prior to the interview.

Even though the Demographic and Health Surveys (DHS) standardize most variables in their published data, this is unfortunately not true for variables on water and sanitation infrastructure. Given the vast array of different technologies used across countries, the detail and structure of the collected information on water and sanitation infrastructure differs widely across the 38 surveys used in this paper. In total, we found about 150 different sanitation and 200 different water codes in our sample. To make the collected information comparable across countries, we developed a few simple coding rules, which map the various types of water and sanitation infrastructure into three broad categories. Since we want to explicitly differentiate between different types of water and sanitation technologies, we follow a coding similar to the water and sanitation ladder proposed by the WHO/UNICEF Joint Monitoring Program (JMP), which is slightly more complex than the improved versus unimproved water and sanitation definition originally suggested by the WHO.

In the first paper of this series (Günther and Fink, 2010) we argue that the health impact of water and sanitation is likely to critically depend on the way in which water and sanitation infrastructure are constructed and used. In the context of sanitation, is seems obvious that the health effects will be larger if excreta are not only kept out of the local water system, but also covered to prevent contact with other vectors; health effects will clearly also depend on hygiene practices. In the case of water, a growing literature suggests that there are large differences between the quality of water at the source and the quality of water at the point of use (for an overview see Wright, 2004; Zwane and Kremer, 2007). While community standpipes and covered ground-water wells and pumps offer clean water, the transport of water to the household as well as the storage of water in the household heavily expose water to contamination, substantially lowering the average quality of water consumed in the household relative to the quality of the water at the (public) source.

The rules we applied for classifying water and sanitation infrastructure are very similar to the three-rung ladder for drinking-water and the four-rung ladder for sanitation suggested by the WHO/UNICEF Joint Monitoring Program (JMP) for Water Supply and Sanitation (see Table 2).[8] The first distinction we make is between *unimproved* and *improved* water sources. Surface water and traditional (unprotected) wells and springs are coded as unimproved water source, while protected springs and wells, boreholes and public standpipes are coded as an improved water source.[9] On top of these two categories, piped water into the household is considered as a separate category to capture the lower risk of water contamination through transport and storage. The distinction is obviously also important from a cost-benefit perspective, as the additional capital investment required for private access is substantial and may not be warranted by additional improvements in child health.

Following a similar logic, we also divide sanitation into three broad categories. We code (flush) toilets connected to either a septic tank or a central sewage system as the (first-) best technology available. The second-best option is improved latrines (private or shared); all other traditional sanitation practices are considered *unimproved.* The Joint Monitoring Program (JMP) further distinguishes between unimproved sanitation techniques (e.g. bucket latrines) and open defecation. We investigated this distinction empirically without finding any significant difference across the two groups in our previous paper (Günther and Fink, 2010), and therefore decided to collapse the two categories for the purpose of this paper. We also deviate marginally from the JMP ladder with respect to improved sanitation. Whereas the JMP groups private flush toilets to a sewage system/septic tank together with improved on-site latrines we distinguish between these two categories, since connected private toilets are

[8] http://www.wssinfo.org/definitions/ladders.html
[9] Several DHS surveys do not distinguish between protected and unprotected wells and springs. Whenever it was not clear from the data whether a spring or well was improved or not we made the assumption that it is unimproved. We therefore might somewhat underestimate the access to improved water technologies and overestimate the costs to reach MDG4 with MDG7 in our estimations (see Section 3).

associated with substantially higher upfront investments (and longer durability) than latrines.[10]

Table 2: Water and Sanitation Categories

Water Infrastructure	JMP ladder	Revised Water ladder for this paper		Sanitation Infrastructure	JMP ladder	Revised Sanitation ladder for this paper
Piped water into hh	piped	piped		Flush to sewage	improved	flush
Public tap	improved	improved		Flush to septic tank	improved	flush
Tubewell/ Borehole	improved	improved		Flush to pit latrine	improved	improved
Protected well	improved	improved		VIP latrine	improved	improved
Protected spring	improved	improved		Pit latrine with slab	improved	improved
Unprotected well	unimproved	unimproved		Shared latrine	shared	improved
Unprotected spring	unimproved	unimproved		Traditional/open pits	unimproved	unimproved
Rainwater	unimproved	unimproved		Pit latrine without slab	unimproved	unimproved
Tanker-truck	unimproved	unimproved		Hanging latrine	unimproved	unimproved
Bottled water	unimproved	unimproved		Bucket	unimproved	unimproved
Surface water	unimproved	unimproved		No facilities	open	unimproved

Even though the water and sanitation coding slightly deviates from our previous paper, it is worth stressing that the differences are mostly conceptual – the impact of recoding on estimated coefficients is marginal at most. We provide a complete list of all water and sanitation infrastructure codes of the 38 DHS surveys, as well as the chosen categories in Appendices 1 and 2.

[10] See Table 9 for details.

Table 3: Water and Sanitation Coverage

		Sanitation Coverage			Water Coverage		
Country	**Year**	**unimproved**	**improved**	**flush**	**unimproved**	**improved**	**piped**
Azerbaijan	2006	0.188	0.470	0.342	0.111	0.428	0.461
Bangladesh	2004	0.438	0.481	0.080	0.037	0.920	0.043
Benin	2006	0.703	0.296	0.001	0.367	0.374	0.259
Bolivia	2003	0.396	0.299	0.305	0.226	0.124	0.649
Burkina Faso	2003	0.849	0.140	0.012	0.456	0.511	0.033
Cambodia	2000	0.842	0.112	0.045	0.777	0.187	0.036
Cameroon	2004	0.707	0.239	0.054	0.383	0.527	0.091
Chad	2004	0.960	0.038	0.002	0.595	0.367	0.038
Congo, Rep.	2005	0.829	0.132	0.039	0.476	0.317	0.207
Dominican	2002	0.117	0.456	0.427	0.130	0.568	0.302
Gabon	2000	0.564	0.235	0.201	0.217	0.389	0.393
Ghana	2003	0.726	0.204	0.070	0.376	0.521	0.103
Guinea	2005	0.752	0.232	0.016	0.402	0.537	0.061
Haiti	2005	0.755	0.211	0.034	0.398	0.519	0.083
India	2005	0.652	0.103	0.245	0.129	0.685	0.186
Indonesia	2002	0.359	0.188	0.453	0.357	0.494	0.149
Kenya	2003	0.860	0.065	0.075	0.615	0.224	0.160
Lesotho	2004	0.805	0.185	0.010	0.305	0.614	0.080
Liberia	2006	0.766	0.167	0.067	0.348	0.630	0.022
Madagascar	2003	0.545	0.444	0.010	0.735	0.238	0.027
Malawi	2004	0.972	0.010	0.019	0.394	0.566	0.041
Mali	2006	0.803	0.181	0.016	0.456	0.457	0.087
Morocco	2003	0.217	0.090	0.693	0.292	0.203	0.505
Mozambique	2003	0.520	0.464	0.016	0.678	0.256	0.066
Namibia	2006	0.610	0.076	0.313	0.132	0.429	0.438
Nepal	2006	0.703	0.085	0.212	0.178	0.687	0.135
Nicaragua	2001	0.697	0.096	0.207	0.274	0.357	0.369
Niger	2006	0.914	0.078	0.008	0.607	0.337	0.056
Nigeria	2003	0.872	0.022	0.106	0.589	0.346	0.065
Pakistan	2006	0.442	0.113	0.446	0.055	0.622	0.322
Peru	2003	0.293	0.332	0.376	0.293	0.127	0.580
Philippines	2003	0.207	0.226	0.567	0.110	0.543	0.347
Senegal	2005	0.586	0.105	0.309	0.334	0.284	0.382
Swaziland	2006	0.701	0.174	0.125	0.346	0.362	0.293
Tanzania	2004	0.956	0.026	0.018	0.557	0.394	0.049
Uganda	2006	0.804	0.190	0.006	0.339	0.631	0.030
Zambia	2001	0.856	0.013	0.130	0.515	0.349	0.136
Zimbabwe	2005	0.441	0.281	0.278	0.278	0.425	0.297
Average		**0.627**	**0.211**	**0.163**	**0.372**	**0.433**	**0.195**

Table 3 shows country-specific access to improved water and sanitation infrastructure following the classification in Table 2. On average, about 63% of the children in our sample do not have access to any form of sanitation (including improved and flush toilets) and about 37% lack access to safe drinking water; figures that are very much in line with estimates by the WHO/UNICEF[11] for Sub-Saharan Africa (68% without access to sanitation and 40% without access to safe drinking water).

3. Methodology

As discussed in the introduction, the analytical work of this paper is divided into three parts. In the first part, we estimate the empirical relation between water and sanitation infrastructure and child mortality. In the second part, we use the model parameters empirically fitted in the first part to predict country-specific aggregate improvements in child mortality that could be achieved by investments in water and sanitation infrastructure. In the last part, we combine our mortality improvement estimates with cost estimates for the required infrastructure upgrades to compute country specific investment needs as well as the implied costs per life-year saved.

The estimation of the mortality effects of water and sanitation infrastructure is based on a logistic model. The dependent variable is the probability of a child under the age of 5 dying during the 12 months preceding the survey. The model we estimate is given by:

$$\left(\frac{p_{ijk}}{1-p_{ijk}}\right) = \beta_0 + \beta_1 W_{1j} + \beta_2 W_{2j} + \beta_3 S_{1j} + \beta_4 S_{2j} + \chi C_{ij} + \delta H_j + \kappa Survey_k + \varepsilon_{ijk} \quad (1)$$

where p_{ijk} is a binary mortality indicator for child i in household j in the DHS survey k. W_1, W_2 are the two indicators marking improved and privately piped water access of the household respectively, and S_1, S_2 are indicators representing improved latrines and flush toilets, respectively. C_{ij} and H_j are vectors of child and household characteristics, and $Survey_k$ are survey fixed effects. Standard errors are adjusted for clustering at the primary sampling unit (cluster) level. The estimated coefficients of equation (1) are reported as odds

[11] http://www.wssinfo.org/

ratios. Odds ratios represent the odds of a child death (for example) with improved sanitation relative to the odds of a child dying without improved sanitation:

$$OR = \frac{\dfrac{P(d)_S}{1-P(d)_s}}{\dfrac{P(d)_U}{1-P(d)_U}} \tag{2}$$

where *P(d)* denotes the probabilities of a child dying with sanitation (*S)* and without sanitation (U), respectively. Odds are different from probabilities as they refer to the probability that an event occurs relative to the probability that an event will not occur, whereas probabilities only represent the probability that an event occurs. For small probabilities the odds (and the respective odds ratio) are, however, very similar to the corresponding probabilities.

We pool all relevant child-year observations in our regressions. The implicit assumption underlying this pooling is that the *marginal reduction* in the mortality risk is the same for all children in the included age range (0-60 months). To adjust for differences in the *absolute mortality risk* driven by different ages of exposure, we include child-age (cohort) fixed effects in our empirical model. In addition, we control for various child level characteristics that are commonly used as predictors for child mortality in the health literature: age, sex, whether the child is the first born, and time intervals (in month) between the preceding and succeeding births.

To deal with omitted variable bias concerns, we include an extensive list of control variables including mother's age and education, mother's marital status, household size, and urban or rural residence. DHS surveys do not contain any direct information on the income or consumption of households. To overcome the lack of a direct income measure, we include household assets as proxies for permanent income. The assets we use in our final specification are electricity, radio, TV, and bicycle. Most DHS surveys include an asset index based on principal component analysis as suggested by Filmer and Pritchett (2001). While these indices do well in describing the relative wealth ranking within a country, asset quintiles are hard to compare across countries with highly heterogeneous income and asset levels. We thus chose to directly control for a set of durable assets available in all surveys.[12] To avoid potential

[12] Other potentially important control variables to limit omitted variable bias are indicators related to health preferences, such as the vaccination status of the child and whether the child was breastfed. The problem with vaccination and breastfeeding in cross-sectional studies is reverse causality: children who die at a very young age will never be vaccinated or breastfed. We could use the vaccination and breastfeeding status of living siblings to approximate or instrument the vaccination and breastfeeding status of dead children. The validity of such an approach is however, debatable, and the improvements achievable in the face of the resulting sample restrictions (identification can only be reached in households with at least two children) are uncertain.

biases resulting from country level confounders correlated with both water and sanitation and child mortality we also control for survey fixed effects.[13]

In a second step, we use the estimated relative mortality reductions to compute the predicted absolute mortality reductions per 1000 live births which would be generated by improving water and sanitation infrastructure under two scenarios: In the first scenario, we assume that eliminating the lack of access to improved water and sanitation is the policy target. Under this "low cost" scenario, we assume that any household currently using surface or unprotected water sources would be upgraded to an improved water source, and any household using open defecation or only unimproved sanitation technologies would get an improved latrine. The second scenario reflects a more ambitious program aiming at upgrading water and sanitation access to the highest possible standard. In this scenario, any household that does not already have access to privately piped water and a toilet connected to a septic tank or sewage system will be provided with such access.

The main question we want to address in this paper is the potential contribution of water and sanitation improvements towards achieving MDG 4. MDG 4 aims at reducing child mortality by two thirds in each country between 1990 and 2015. Based on the 1990 child mortality levels (World Population Prospects, United Nations Population Division), we first assign an under-5 mortality target for 2015 to each country. In a second step, we look at the latest mortality numbers and evaluate the potential contribution of investment in water and sanitation infrastructure towards achieving MDG 4. To do so, we compare the predicted absolute mortality reduction under scenarios 1 and 2 to the observed gap between the country-specific 2015 target and under-5 mortality as estimated in the most recent DHS surveys. The expected contribution of water and sanitation under each scenario for each country is then given by:

$$MDG\,contribution = \frac{CM_{DHS} - CM_{cf}}{CM_{DHS} - CM_{MDG}} \tag{3}$$

where CM_{DHS} is under-5 child mortality in the most recent DHS survey, CM_{cf} is the predicted (counterfactual) child mortality rate, and CM_{MDG} is the country-specific child mortality rate target set in the MDGs. From the estimated absolute reductions in child mortality rates we can also derive the total number of deaths prevented (DP) per year and

[13] Due to a lack of computational power, we were unfortunately not able to control for regional (sub-national) fixed effects in our estimation. But as we show in a previous paper (Günther & Fink, 2010) the inclusion of regional fixed effects has little impact on the point estimates obtained.

country under the assumption that every household in a developing country would be given access to simple or more advanced water and sanitation technologies:[14]

$$DP = birth\frac{CM_{DHS} - CM_{cf}}{1000} \qquad (4)$$

where *DP* is the absolute number of deaths prevented and *birth* is the absolute number of children born per year in a given country. Following the methodology proposed by Mathers et al. (2001), we can convert the number of deaths prevented into a (discounted) sum of life-years saved (LYS):

$$LYS = DP\frac{1-(\frac{1}{1+\delta})^{n}}{1-(\frac{1}{1+\delta})} \qquad (5)$$

where *n* is the standard (global) life expectancy at age 5 – our proxy for years lost due to death at age 5 - and δ is the discounting rate for future years lived. As suggested by Mathers et al. (2001), we assume a 3 percent discount rate, uniform age weights and a standard life expectancy of 75 at the age of 5.

Last, we combine investment and maintenance costs and durability estimates of various categories of water and sanitation infrastructure (WHO/UNICEF, 2000; Hutton and Haller, 2004; Clasen et al., 2007; see Table 9 for details) with the national coverage levels displayed in Table 3, to compare the expected costs under the two scenarios to the expected benefits in terms of life-years saved. The estimated costs per life-year saved under a given scenario can be computed as

$$Cost\ per\ LYS = \frac{[cost_S(1-Cov_S)+cost_W(1-Cov_W)]HH}{LYS[1-(\frac{1}{1+\delta})^{T}]/[1-(\frac{1}{1+\delta})]} \qquad (6)$$

where $cost_S, cost_W$ are the investment and (discounted) maintenance costs for sanitation and water infrastructure over the estimated life time. Cov_s, Cov_W are the fractions of household with appropriate sanitation and water access prior to the interventions, and *HH* is the total number of households in the country. Similar to equation (5), δ is the discounting rate for future years lived, which we fix at 3%. *T* is the number of years the water and sanitation infrastructure of interest is expected to last.

[14] Child mortality reflects the likelihood of a child born in period *t* dying in the period *t* to *t+5*. Under the simplifying assumption that the previous cohorts are of approximately the same size as the one born in a given year, it is easy to see that deaths prevented in a given year can be expressed as in equation (4).

Our methodology is conceptually quite different from previous epidemiological estimates on preventable child deaths through investments in water and sanitation infrastructure (Clasen et al., 2007; Pruess et al., 2002; Pruess-Uestuen et al., 2008). While these existing studies share our objective of quantifying the mortality improvements achievable with water and sanitation investment in developing countries, the way of deriving these estimates differs greatly. Rather than directly deriving the marginal mortality improvements generated by access to water and sanitation infrastructure across a large set of national representative surveys, most existing studies start from an estimated total distribution of mortality causes and combine them with local experimental intervention studies about the impact of water and sanitation on fecally-transmitted diseases. The implicit assumptions are that intervention studies have external validity and are scalable, and also that the mortality impact of improved water and sanitation can be derived directly from related morbidity numbers.

The main advantages of the approach chosen in this paper are twofold: first, as mentioned before, the average treatment effects estimated in this paper allows us to avoid external validity and scalability concerns surrounding intervention studies. Second, we can directly estimate mortality reductions without having to rely on a theoretical framework to translate diarrhea prevalence into actual mortality outcomes. That is, by analyzing the aggregate mortality impact we can also capture the impact through diseases for which no intervention studies on water and sanitation exist (Pruess-Uestuen et al., 2008).

Notwithstanding these advantages, it is clear that the framework applied in this paper also rests on a large set of assumptions: by estimating the effects of water and sanitation in a pooled sample, we implicitly impose that the marginal impact is constant across countries and age groups. While this assumption is clearly an oversimplification, it should not bias our results in any specific direction, and greatly facilitates the benefit-cost calculations in the following section. Another problem of our methodology could be endogeneity leading to an overestimation of the impact of water and sanitation on child mortality.

4. Results

4.1 Reductions in Under-5 Mortality

Table 4: Descriptive Statistics

Variable	Mean	Std. Dev.	Min	Max
Died in last year	0.021		0	1
Water and Sanitation Infrastructure				
Open/uncovered defecation	0.596		0	1
Improved sanitation	0.224		0	1
Privately flush toilet	0.180		0	1
Open/unprotected water	0.349		0	1
Improved water	0.441		0	1
Privately piped	0.210		0	1
Child Characteristics				
First born child	0.246		0	1
Birth spacing before (months)	30.412	27.258	0	338
Birth spacing after (months)	7.658	13.556	0	59
Female	0.492		0	1
Age child (in month)	28.594	17.293	0	59
Mother's Characteristics				
Mother no education	0.388		0	1
Mother primary education	0.339		0	1
Mother secondary education	0.229		0	1
Mother tertiary education	0.044		0	1
Currently married	0.770		0	1
Age mother (in years)	28.497	6.758	14	49
Household Characteristics				
Household size	7.076	4.045	1	74
Electricity	0.403		0	1
Radio	0.587		0	1
TV	0.317		0	1
Bike	0.342		0	1
Urban residence	0.345		0	1

Notes: For all variables, the number of observations is 306,642.

Table 4 provides summary statistics for our sample. The sample contains 306,642 observations for children under the age of 5 at the date of the interview. The average probability of death is 0.02, which translates into approximately 100 under-5 deaths per 1000 children born. 60% of children live in households without sanitation, while 35% of children live in households without access to an improved water source. The average household in our sample is poor: less than half of all households have electricity, own a TV or a bike. Average parental educational attainment is similarly low: 39% of mothers have no education, and only 27% of mothers have secondary or higher education. Only 35% of children live in urban areas, highlighting the limited degree of urbanization in the developing country sample analyzed.

Table 5: Logistic Regression: Under-5 Child Mortality

	Odds Ratio	Std. Err.	P>z
Water and Sanitation Infrastructure			
Open/uncovered defecation	*Reference group*		
Improved sanitation	0.921	0.038	0.044
Private flush toilet	0.842	0.052	0.006
Open/unprotected water	*Reference group*		
Improved water	0.954	0.031	0.156
Private piped connection	0.842	0.047	0.002
Child Characteristics			
First born child	0.961	0.047	0.412
Birth spacing before	0.996	0.001	0.000
Birth spacing after	0.954	0.005	0.000
Female	0.897	0.024	0.000
Age 0-11 months	*Reference group*		
Age 12-23 months	0.467	0.016	0.000
Age 24-35 months	0.191	0.009	0.000
Age 36-47 months	0.070	0.005	0.000
Age 48-59 months	0.033	0.003	0.000
Mother's Characteristics			
Age mother	0.934	0.014	0.000
Age mother squared	1.002	0.000	0.000
Mother primary education	0.893	0.033	0.002
Mother secondary educ.	0.670	0.033	0.000
Mother tertiary education	0.410	0.053	0.000
Currently married	0.757	0.030	0.000
Household Characteristics			
Household size	0.907	0.006	0.000
Electricity	0.878	0.044	0.010
Radio	1.120	0.034	0.000
TV	0.946	0.043	0.228
Bike	1.050	0.033	0.123
Urban residence	0.973	0.038	0.487

Notes: Based on a sample of 306642 observations. Empirical model includes survey fixed effects as described in equation (1).

Table 5 shows the estimation results based on equation (1) – the estimated coefficients are presented as odds ratios. Relative to households with unimproved water and sanitation, improved sanitation reduces the odds of dying by 7.9%;[15] the effect of a private flush toilet is

[15] The odds ratio of 0.921 corresponds to the odds of dying below the age of 5 in any given year with improved sanitation divided by the odds of dying without improved sanitation. Improved sanitation hence decreases the

approximately twice as big with a reduction of the odds of dying by 15.8%. The results for improved water infrastructure are similar, with a reduction of the odds of dying by 4.6% for improved wells or springs and 15.8% for piped water into the household. The estimated effects for the included control variables appear consistent with our prior assumptions both regarding the expected sign and magnitudes of coefficients. In terms of its protective effect, the single most important factor appears to be mother's education, with odds ratios ranging between 0.89 for primary and 0.41 for tertiary education.

Even though the data set used in this paper is substantially more restricted in terms of temporal and spatial coverage than a previous paper of us (Günther and Fink, 2010),[16] the estimates reported in Table 5 look overall very similar to our prior estimates. With the more restrictive coding rules applied in this paper, the marginal effects of piped water and flush toilets are slightly larger; the difference in the estimated coefficients is, however, not significant.

4.2 Aggregate Mortality Effects and Contribution to MDG 4

Having estimated an empirical relation between water and sanitation infrastructure and child mortality, we can compute predicted mortality under the counterfactual assumption that all children in our sample are provided with access to improved water and sanitation. Given that we distinguish between three levels of water and sanitation, we consider two alternative scenarios: In the first scenario, we assume that all children are provided with access to basic improved water and sanitation. In the second scenario, we assume that all children are provided with access to the highest quality water and sanitation infrastructure, i.e. water pipes and flush toilets in their households.

To see how these assumptions translate into changes in mortality, we first predict mortality under the true (observed) distribution of water and sanitation access, which, by construction, yields current mortality rates. In a second step, we recode all water and sanitation variables to reflect the counterfactual assumptions, and predict child mortality under the assumption that all other child, household and survey characteristics remain unchanged. We apply the DHS country-specific survey weights for these mortality calculations.

Table 6 shows the results of these counterfactual computations. In column 1 of Table 6, we show current under-5 child mortality rates (deaths per 1000 live births) as measured in the

odds of dying by 7.9%: (1-0.921)*100. Given the "small" probability of child death within a given year in general (0.021, Table 4), odds ratios are very similar to probability ratios in this case.

[16] See Section 2 for a more detailed discussion on sample selection.

most recent DHS survey for each country. These numbers are, in general, very similar to the mortality numbers published by the WHO and the World Bank with the notable exception of Niger and Liberia, where the mortality estimates from the DHS appear significantly lower than the official WHO figures.[17] In column 3 of Table 6, we show the calculated child mortality rates for counterfactual scenario 1 (basic improved water and sanitation), while we show imputed child mortality rates under counterfactual scenario 2 (privately piped water and flush toilets) in column 4 of the table.

The average expected decrease in child mortality obtained from upgrading households to at least basic improved water and sanitation (counterfactual scenario 1) is 11 deaths per 1000 in Sub-Saharan African countries, and approximately 4 deaths per 1000 children born in the other developing countries in our sample (Table 6, column 5). Under scenario 2 – upgrading all households to private water connections and flush toilets – the effects are substantially larger. On average, we get a reduction in under-5 mortality of 31 deaths per 1000 in Sub-Saharan Africa, and a reduction of 14 deaths per 1000 children born for other countries in our sample (Table 6, column 6).

Table 6 also highlights the heterogeneity in the mortality effect of water and sanitation upgrades across regions and countries. The potential of reducing child mortality through improved water and sanitation technologies does not only depend on the existing stock of water and sanitation infrastructure, but also on the child mortality levels in the country of interest. As shown in columns (5) and (6) of Table 6, the highest absolute decreases in mortality are predicted for Nigeria and Chad, with predicted reduction in under-5 mortality of 46 and 50 deaths per 1000, respectively. These numbers are the result of both low levels of existing infrastructure and high current mortality rates. In comparison, the predicted improvements appear small for countries like Peru or the Philippines, where baseline child mortality levels are relatively low, and water and sanitation coverage rates are already relatively high.

[17] The under-5 mortality estimates reported by the WHO in 2005 are 262 for Niger and 235 for Liberia. But these estimates appear to be based on earlier survey data. See http://www.who.int/healthinfo/statistics/mortchildmortality/en/index.html for details.

Table 6: Reduction in Mortality and Contribution to MDG 4

	Under-5 mortality (deaths per 1000 live births)				Lives saved per 1000 live births		% contribution to MDG 4	
	(1) Baseline	(2) MDG 4 target	(3) Counter-factual I	(4) Counter-factual II	(5) Counter-factual I	(6) Counter-factual II	(7) Counter-factual I	(8) Counter-factual II
Sub-Saharan African Countries								
Benin	107	62	100	84	8	23	0.166	0.513
Burkina Faso	173	69	159	132	14	42	0.132	0.398
Cameroon	153	46	142	118	11	35	0.102	0.328
Chad	204	67	186	154	18	50	0.134	0.366
Congo, Rep.	132	34	121	101	11	31	0.116	0.318
Gabon	98	31	92	79	6	19	0.088	0.278
Ghana	123	40	114	94	9	29	0.111	0.347
Guinea	153	78	141	117	11	36	0.153	0.484
Kenya	113	32	103	86	11	28	0.131	0.342
Lesotho	129	34	119	99	10	30	0.100	0.318
Liberia	107	78	99	81	8	25	0.277	0.894
Madagascar	96	56	89	72	7	24	0.184	0.588
Malawi	120	74	110	90	11	30	0.230	0.650
Mali	174	83	160	133	14	41	0.151	0.452
Mozambique	166	78	155	128	12	38	0.133	0.437
Namibia	70	29	66	57	4	13	0.103	0.311
Niger	152	107	138	114	14	38	0.310	0.843
Nigeria	195	77	178	149	17	46	0.143	0.390
Senegal	101	50	94	82	7	19	0.131	0.376
Swaziland	158	37	147	126	11	33	0.091	0.269
Tanzania	105	54	95	78	10	27	0.195	0.526
Uganda	141	53	131	107	10	34	0.119	0.384
Zambia	186	60	170	142	16	44	0.129	0.348
Zimbabwe	102	25	97	83	5	19	0.070	0.252
Average	**136**	**56**	**125**	**104**	**11**	**31**	**0.146**	**0.434**
Other Developing Countries								
Azerbaijan	58	35	57	50	1	8	0.055	0.347
Bangladesh	83	50	80	66	3	18	0.100	0.530
Bolivia	81	42	77	69	4	12	0.101	0.311
Cambodia	131	39	118	97	13	34	0.137	0.364
Dominican	37	22	36	32	1	6	0.048	0.358
Haiti	113	51	105	86	9	27	0.140	0.432
India	76	38	71	60	5	16	0.127	0.427
Indonesia	54	30	51	44	3	10	0.114	0.431
Morocco	52	30	50	45	2	7	0.089	0.298
Nepal	79	47	73	62	5	17	0.168	0.547
Nicaragua	48	23	44	38	4	10	0.146	0.410
Pakistan	125	43	120	104	5	21	0.065	0.251
Peru	47	26	44	39	2	8	0.109	0.363
Philippines	52	21	51	44	2	8	0.048	0.248
Average	**74**	**35**	**70**	**60**	**4**	**14**	**0.103**	**0.380**

Notes: Column 5 = Column 1- Column 3; Column 6 = Column 1- Column 4; Column 7 = (Column 1- Column 3)/(Column 1- Column 2); Column 8 = (Column 1- Column 4)/(Column 1- Column 2).

With respect to the gap between the MDGs and current mortality rates, we find that providing all children with access to basic improved water and sanitation could close about 15% of the current difference in Sub-Saharan Africa, and 10% in the average country of our sample (Table 6, column 8). Upgrading to private water connections and flush toilets (scenario 2) would close approximately 43% of the remaining gap in Sub-Saharan Africa, and 38% for the rest of the world in our sample (Table 6, column 8).

Given the pronounced differences in the estimated absolute mortality impact, the large variations in the expected contribution towards MDG 4 are not very surprising. The two countries with the highest potential contributions are Liberia and Niger, where we estimate that over 80% of the remaining gap could be closed by investment in sewers and piped water infrastructure. It is worth pointing out that the gap between status quo and the MDG target remains large for most countries, so that even countries with substantial improvements through water and sanitation would remain unlikely to actually achieve the (ambitious) MDG targets.

Nevertheless, the potential impact of water and sanitation on global health in general, and child mortality in particular, is remarkably large. In our sample of 38 developing countries - which covers about 62 million of the 102.5 million children born per year in developing countries - we estimate that private water connections and flush toilets could potentially save up to 1.3 million child lives per year. This corresponds to approximately 20% of the total estimated number of 6 million children under the age of five who die each year in the 38 countries in our sample (Table 7). Assuming that the health improvements are roughly comparable in the rest of the developing world, this means that investment in high-end water and sanitation could save up to 2.2 million child lives in developing countries (World Population Prospects, United Nations Population Division). Plugging the previous estimates into equation (5), and assuming a discount rate of 3% and a global life expectancy of 80 years (i.e. a life expectancy of 75 years at the age of 5), this implies a total of 39.5 million life-years per cohort in the countries covered in this paper, and a total of 66 million life-years in all developing countries combined (Table 7, last column).

Table 7: Discounted live years lost per year (in 000)

			Lives Saved		% of Mortality Reduction		LYS	
	(1) Births	(2) Deaths	(3) Counter-factual I	(4) Counter-factual II	(5) Counter-factual I	(6) Counter-factual II	(7) Counter-factual I	(8) Counter-factual II
SSA Average	705	103	9	26	0.088	0.263	269	767
SSA Sum	16'931	2'476	215	613			6'445	18'397
Other Average	3'224	255	14	50	0.054	0.183	419	1'505
Other Sum	45'130	3'573	196	702			419	1'503
Total Average	1'633	159	11	35	0.073	0.228	324	1'039
Total Sum	62'060	6'049	410	1'316			12'315	39'467

Notes: LYS: Life-year saved. Calculation of LYS based on 3 percent time discounting and uniform age weights and standard life expectancy at age 5 (Mathers, et al., 2001). No difference was made between males and females.

To provide a better sense of the magnitude of these potential benefits in terms of impact on child mortality, we construct two alternative policy counterfactuals (scenarios III and IV) where we focus on mothers' education rather than on water and sanitation infrastructure. One of the most robust findings in the analysis of factors associated with child mortality risks is the large protective effect of maternal education (Ruthstein, 2000). The potential contribution of water and sanitation improvements to achieve MDG 4, as shown in Table 6, may be better appreciated when compared with an alternative policy focusing on maternal education.

Table 8 shows the results of this additional counterfactual exercise: for counterfactual III we assume that that all mothers attain at least some primary education, while for counterfactual IV we assume that all mothers receive at least some secondary education. Even though primary education of the mother is as protective as basic sanitation and water access combined, the aggregate child mortality reductions that would be feasible to achieve via investments in primary education appear small in comparison to the reductions achievable via investments in water and sanitation. The major reason is that many more children lack access to improved sanitation (about 60%), while the percentage of mothers without at least primary education has rapidly declined over the past decades (less than 40% in our sample).

In order to achieve improvements similar in magnitude to the expected improvements with a comprehensive coverage of piped water and flush toilets, all mothers in our sample would have to receive at least some secondary education. With only 27% of mothers currently having attained secondary or higher education, and only about 20% of households currently having access to water and sanitation, the necessary increase in education appears no less ambitious than the required improvements in water and sanitation infrastructure.

Table 8: Investment in Education vs. Investment in Water and Sanitation

	Lives saved by 1000 live births				**% contribution to MDG 4**			
	Counter-factual I	Counter-factual II	Counter-factual III	Counter-factual IV	Counter-factual I	Counter-factual II	Counter-factual III	Counter-factual IV
SSA	11	31	6	31	0.146	0.434	0.087	0.444
Other Countries	4	14	2	16	0.103	0.380	0.069	0.427

Notes: Counterfactual I: scenario basic improved water and sanitation. Counterfactual II: scenario high end improved water and sanitation. Counterfactual III: scenario primary education for mothers. Counterfactual IV: scenario secondary education for mothers.

4.3 Cost-Effectiveness Analysis of Investments in Water and Sanitation

Even though the potential contributions of investment in water and sanitation towards achieving MDG 4 and reducing child mortality appear large, the analysis presented in section 4.2 does not provide any insights into the cost-effectiveness of the suggested policy options. To address this issue, we compute costs per life-year saved, and compare it to the countries' annual GDP per capita. According to the WHO, a health intervention is considered as cost-effective if the costs per life-year saved are smaller than current GDP per capita of this country.[18,19]

In Table 6, we measure mortality effects in terms of the fraction of children from each cohort that die before the age of 5. To establish the absolute number of deaths saved per year we first multiply the child deaths per 1000 prevented with the size of the cohort born in the baseline (see equation (4) and Table 7). To get the number of life-years saved per year we have to multiply the number of deaths prevented times the standard life expectancy at the age of death (75 years). Future life-years are discounted at 3%, so that 75 years of life expectancy translate into about 30 life-years in net-present-value terms (see equation (5) and Table 7) [20]. Since water and sanitation infrastructure protects more than one birth cohort, the estimated number of life-years saved needs to be multiplied with the (discounted) number of years the

---

[18] http://www.who.int/choice/costs/CER_thresholds/en/index.html

[19] While it may appear strange from a humanitarian perspective to differentially value child lives across countries, the simplifying assumption underlying this proposition is that the minimum value of one life-year saved for the society is the output the person would have produced in a given year.

[20] For reasons of simplicity we assume that all children do not die before the age of 5. Our estimates are therefore a rather conservative estimate of life-year saved, the difference to an exact consideration would however, be marginal. A discounted life expectancy of 80 years would for example "only" translate into 31 life-years in net-present-value terms.

infrastructure is estimated to last (see denominator in equation (6)). The durability of water and sanitation infrastructure depends on a large set of local factors, resulting in average durability estimates between 10 and 50 years as shown in columns (3) and (6) of Table 9.

In order to assign cost figures to these estimated health benefits, we furthermore need to translate risk reductions at the child level into local infrastructure needs. Water and sanitation are generally accessed at the household level. The key figure of interest is therefore the number of households that have to be provided with water and sanitation infrastructure in order to assure that each future new-born child has access to any kind of improved water and sanitation infrastructure.

Under the simplifying assumption that each household has some positive probability of having a young child, it is easy to see that the number of households needing access to improved water and sanitation infrastructure is given by the number of households, which in turn is given by the population size N divided by the average household size in the country of interest (Table 10, column (2)). The calculated numbers in column (2) of Table 10 would, however, assume that none of the households in a country already has access to improved water and sanitation infrastructure. In order to adjust for this, the number of households is multiplied by the share of households that do not have yet access to improved water and sanitation facilities (see nominator in equation (6)).

This translates to assuming that all current households not having access to water and sanitation infrastructure need to be equipped with water and sanitation facilities. This is clearly a conservative assumption, since only about 75% of households in our sample currently include women in their childbearing years, and even with changing household composition over time, some households may never have children under the age of five.

Table 9: Infrastructure Costs

	Hutton & Haller (2004) Per Person			Chosen Cost and Time Levels Per household				(8)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	
	Invest. ($)	Yearly Maint. ($)	Life Time (years)	Invest. ($)	Yearly Maint. ($)	Life Time (years)	Discount Rate	Costs per HH over life time
				Sub-Saharan Africa				
Basic san	39-57	4.88-6.21	10-30	399	43	10	3%	781
Basic wat	21-31	1.55-2.4	10-30	161	17	10	3%	309
Flush	120	4.84-10.03	30-50	840	70	25	3%	2099
Piped	102	8.34-12.75	30-50	714	89	25	3%	2315
				Asia				
Basic san	26-50	3.92-5.70	10-30	300	34	10	3%	600
Basic wat	22-64	1.63-4.95	10-30	102	30	10	3%	363
Flush	154	5.28-11.95	30-50	924	72	25	3%	2210
Piped	92	5.97-9.95	30-50	552	60	25	3%	1623
				Latin-America				
Basic san	52-60	6.44-12.39	10-30	312	74	10	3%	965
Basic wat	41-55	3.17-4.07	10-30	330	24	10	3%	545
Flush	160	6.46-13.38	30-50	960	80	25	3%	2400
Piped	144	9.06-15.29	30-50	864	92	25	3%	2509

Notes: Per person investment, operational costs per year and suggested operations times are taken from Hutton and Haller (2004) and WHO/UNICEF (2000). Cost estimates were converted to net present values costs per household based on a 3 percent discount rate and average regional household size.

We base our regional cost estimates for water and sanitation infrastructure on information provided by several recently published papers (WHO/UNICEF, 2000; Hutton and Haller, 2004; Clasen et al., 2007). Since we want to provide an estimate under the most conservative assumptions, we select the highest suggested initial investment cost as well as the highest suggested maintenance costs, and also take the lower end for the durability estimates as the basis for our calculation. As shown in the last column of Table 9, this implies region-specific cost estimates of around US$ 300 per household for basic improved water infrastructure, and US$ 800 for latrines over a life time of 10 years. We assume costs of US$ 2100-2400 and US$ 1600-2500 per household for flush toilets and privately piped water, respectively, with a durability of 25 years (Table 9, last column).

The main results of our cost-benefit analysis are displayed in Table 10. In columns (1) and (2) we show the most recent numbers available for income per capita and the total number of households for each of the 38 countries in our sample. In columns (3) and (4), we convert the country and scenario specific mortality improvements displayed in Table 6 into discounted number of life-years saved over the infrastructure time. Columns (5) and (6) are obtained by dividing the total estimated cost of necessary water and sanitation upgrades by the total number of life-years saved. Last, in columns (7) and (8) we show costs per life-year saved relative to each country's income per capita.

Table 10: Cost Effectiveness of Infrastructure Intervention

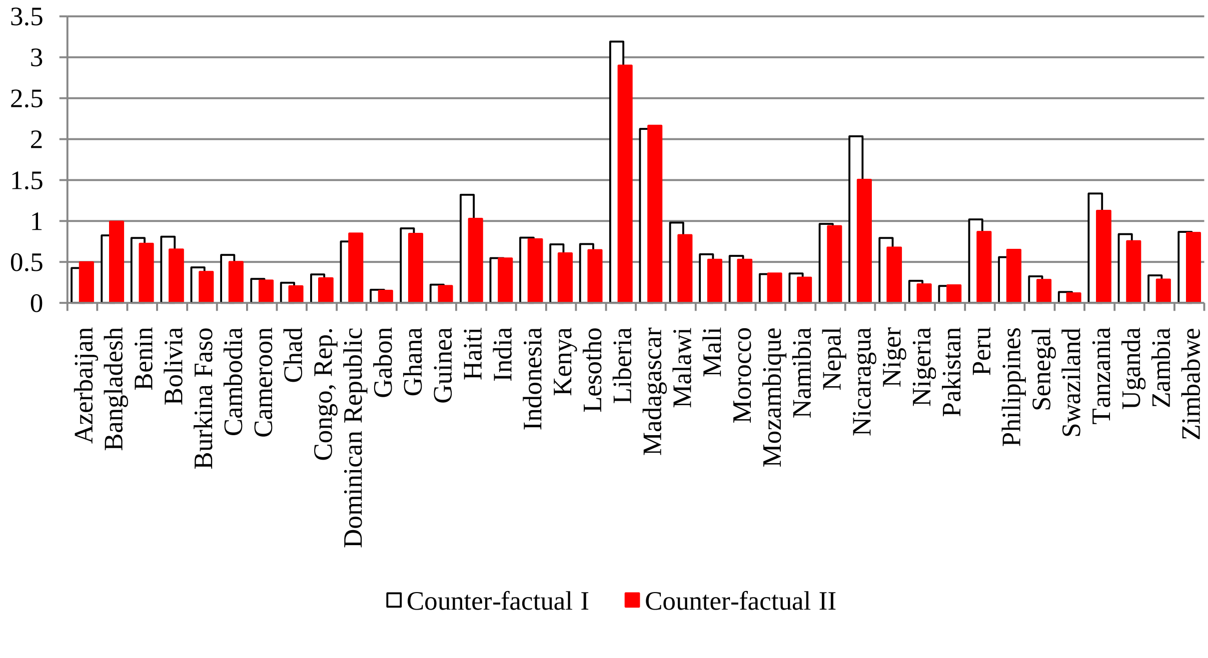
			LYS over infrastructure life time		Cost per LYS		Cost per LYS/ GDP per capita	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	GDP per capita	# of HH	Counter-factual I	Counter-factual II	Counter-factual I	Counter-factual II	Counter-factual I	Counter-factual II
Sub-Saharan African Countries								
Benin	1'412	1'202'279	711'989	4'495'04	1'118	1'020	0.792	0.722
Burkina Faso	1'382	1'377'871	1'847'5	11'328'7	599	524	0.434	0.380
Cameroon	2'602	2'060'683	1'818'8	11'881'8	759	709	0.292	0.273
Chad	2'440	1'330'150	2'060'7	11'496'9	602	500	0.247	0.205
Congo, Rep.	3'338	561'798	386'290	2'167'61	1'156	999	0.346	0.299
Gabon	7'860	150'655	60'762	393'238	1'258	1'180	0.160	0.150
Ghana	1'653	3'720'539	1'690'4	10'756'4	1'503	1'394	0.909	0.843
Guinea	3'584	1'128'451	1'009'9	6'498'34	795	736	0.222	0.205
Kenya	2'024	5'726'210	3'401'1	18'156'3	1'451	1'226	0.717	0.605
Lesotho	2'335	283'228	122'190	792'495	1'676	1'504	0.718	0.644
Liberia	386	491'754	281'789	1'858'21	1'231	1'118	3.193	2.898
Madagascar	856	3'115'578	1'117'7	7'280'59	1'819	1'853	2.125	2.164
Malawi	1'254	2'362'637	1'690'0	9'756'03	1'231	1'037	0.981	0.827
Mali	1'273	1'844'262	1'875'7	11'460'9	754	672	0.593	0.528
Mozambique	2'219	2'986'425	2'358'8	15'844'0	780	797	0.351	0.359
Namibia	6'395	299'410	67'252	414'542	2'303	1'980	0.360	0.310
Niger	860	1'703'163	2'253'7	12'525'4	681	580	0.792	0.675
Nigeria	2'528	18'131'86	22'860'	127'254'	684	576	0.271	0.228
Senegal	1'901	868'597	792'169	4'661'29	615	537	0.324	0.283
Swaziland	7'297	149'867	101'967	615'404	961	846	0.132	0.116
Tanzania	922	5'440'341	4'058'1	22'369'1	1'232	1'037	1.337	1.125
Uganda	1'171	4'383'562	3'273'0	21'557'0	981	881	0.838	0.753
Zambia	1'978	1'780'822	2'208'2	12'146'1	667	561	0.337	0.283
Zimbabwe	1'894	2'188'552	574'408	4'245'19	1'640	1'620	0.866	0.855
Average	**2'482**	**2'637'029**	**2'359'3**	**13'748'1**	**1'104**	**995**	**0.722**	**0.655**
Other Developing Countries								
Azerbaijan	10'298	1'431'741	50'251	650'850	4'366	5'126	0.424	0.498
Bangladesh	2'341	22'152'88	3'171'1	34'135'5	1'931	2'327	0.825	0.994
Bolivia	3'779	1'569'231	259'619	1'626'21	3'053	2'458	0.808	0.650
Cambodia	2'824	2'263'242	1'077'4	5'865'53	1'654	1'417	0.586	0.502
Dominican	9'665	1'699'809	42'949	647'441	7'260	8'205	0.751	0.849
Haiti	1'581	1'334'898	603'659	3'794'56	2'090	1'625	1.322	1.028
India	3'825	159'590'0	33'342'	229'447'	2'098	2'079	0.548	0.544
Indonesia	5'186	40'108'89	3'344'3	25'826'8	4'138	4'022	0.798	0.776
Morocco	5'419	4'314'286	327'947	2'242'89	3'108	2'851	0.573	0.526
Nepal	1'932	4'038'748	1'056'3	7'001'79	1'860	1'814	0.963	0.939
Nicaragua	2'177	726'375	134'836	774'140	4'427	3'271	2.033	1.503
Pakistan	3'589	18'331'37	7'035'4	55'122'4	743	773	0.207	0.215
Peru	6'400	4'545'455	308'230	2'088'63	6'518	5'554	1.018	0.868
Philippines	4'791	13'360'12	818'896	8'682'46	2'681	3'103	0.560	0.648
Average	**4'558**	**19'676'22**	**3'683'8**	**26'993'3**	**3'281**	**3'188**	**0.816**	**0.753**

Notes: Calculation of life-years saved (LYS) are based on a 3% discount rate, uniform age weights and an average life expectancy of 75 years at the age of 5 (premature death). Same life expectancies and mortality effects are assumed for males and females. Income per capita numbers are in real 2007 dollars at PPP from the Penn World Tables 6.3 (Heston et al, 2009).

Our results suggest that the average cost per life-year saved is significantly below income per capita. Somewhat surprisingly, privately piped water and flush toilets appear to be slightly more cost-effective due to their superior durability and their larger protective effect. On average, we find that the cost per life-year saved is between 65 and 72 percent of yearly income per capita in Sub-Saharan Africa and between 75 and 82 percent of yearly income per capita in the other developing regions.

In Figure 1, we plot the costs per life-year saved for the two scenarios relative to GDP per capita (Table 10, column (7) and (8)). Water and sanitation infrastructure investment appear particularly cost-effective in Swaziland and Gabon, were we estimate the cost per life-year saved to be below 20% of real income per capita. Out of the 38 countries in our sample, only 5 countries have cost ratios over one for water and sanitation investment. The only country with a cost to GDP ratio in excess of 3 is Sierra Leone, where the infrastructure costs appear simply too large when compared to a rather dismal GDP per capita estimate of US$ 386 in 2007.

Figure 1: Cost per LYS relative to GDP per Capita 2007



Last we compare the investments necessary to achieve the maximum number of life-years-saved, i.e. providing all households with access to improved sanitation, with current total bi- and multilateral development aid received per year. We estimate that for scenario 1 (providing all households with basic water and sanitation technologies) the average total costs per country and year are 147 million US$, which is 17%[21] of the average development aid (880 million US$) received by the countries in our sample in 2009.[22] For scenario 2 (providing all households with high-end water and sanitation technologies) the estimated average costs amount up to 347 million US$ or about 40% of current development aid received per country and year.

It is worth highlighting that all of the cost-benefit ratios presented here are likely overstating the true cost, and understating the true benefit of water and sanitation investment for two main reasons: First, as we have made clear in the preceding section, we have selected the upper-bound cost estimates from Hutton and Haller (2004) to avoid underestimating the true cost of providing infrastructure.[23] Second, and more importantly, our mortality estimates only capture the direct child mortality effects of water and sanitation infrastructure, that is, the private mortality benefits that accrue at the child or household level, without taking into account any positive externalities, and without taking into account morbidity effects. Water, and in particular sanitation, can be presumed to have substantial positive spillovers within clusters and neighborhoods (see also Günther and Fink, 2010). Improved water and sanitation can also be assumed to be associated with considerable improvements in morbidity and overall well-being. The cost-benefit ratios presented in this paper should thus be viewed as a lower bound, since the benefit estimates shown are likely to underestimate the true social benefits of water and sanitation, while the cost estimates are likely to overstate the true financial commitment required for their provision.

5. Discussion and Conclusion

In this paper we have used micro-data from 38 developing countries to estimate the mortality effects of water and sanitation, and to quantify the degree to which improvements in water and sanitation infrastructure could contribute to achieving the mortality objectives established in the Millennium Development Goals. We have shown that the mortality gains from improved water and sanitation are large: on average, access to improved water and sanitation lowers the odds of a child dying before the age of five by about 5 to 8 percent, while private access to piped water and toilets connected to a septic tank or sewage system can reduce the odds of early child mortality by about 16 percent.

[21] This figure excludes India, Nigeria, Bangladesh and Indonesia; given that these countries receive very low development aid per capita, their inclusion would have led to misleadingly high ratios of water and sanitation investment costs relative to international development aid.
[22] OECD Statistics: http://stats.oecd.org/Index.aspx?DatasetCode=ODA_RECIP#
[23] Note that the cost data from Hutton and Haller (2004) reflect estimates from 2000.

Our calculations suggest that on average the provision of improved water and sanitation could reduce child mortality by about 8 children per 1000; providing private water connections and flush toilets to every child's home would reduce mortality by an average of 25 deaths per 1000 live births, with improvements in excess of 50 deaths per 1000 in some Sub-Saharan African countries. All developing countries combined, we estimate that a complete access to high-end water and sanitation infrastructure could reduce child mortality by about 20% and prevent 2.2 million deaths under the age of 5 per year in the developing world.[24] In terms of the MDG mortality targets, this implies that investment in water and sanitation could cover more than a quarter of the gap between current morality and the MDG 4 objectives.

It is worth stressing that the mortality effects estimated in this paper are well below the figures associated with the historical mortality contribution of water and sanitation infrastructure in Europe and the Americas. Several independent studies point towards child mortality reductions of up to 50 to 75 percent generated by improvements in water and sanitation (see Woods et al., 1988; Szreter, 1988; Cutler and Miller, 2005; Deaton, 2006; Aiello et al., 2008). While today's mortality environment in developing countries may not be directly comparable to Europe in the late 19th century or the US in the early 20th century, it is interesting to point out that the mortality improvements reported in this paper seem low, rather than high, from a long-term perspective, and are very much in line with intervention based epidemiological evidence (see e.g. Pruess-Uestuen et al., 2008).

While one may argue that the estimated coefficients might be upward-biased due to omitted confounding variables, it is important to stress that we chose all assumptions in this paper in a way to get to a lower bound of the cost-benefit ratios. This is not only because we chose the most conservative cost and durability assumptions throughout, but, because we have also ignored spillover effects, by estimating the mortality effects at the household level; such spillovers may be large from a welfare perspective, and are particularly relevant for the case of sanitation (see also Günther and Fink, 2010). More importantly, the welfare improvements made by water and sanitation clearly go far beyond child mortality; providing a healthier environment to children is likely to not only affect their short-term, but also their long-term physical and mental development, labor-force productivity, and lifetime earnings. Needless to say that providing better water and cleaner environments will not only benefit children, but also the rest of society both in terms of their health and in terms of comfort and overall living standards.

[24] Excluding China.

From a policy perspective, the relatively high upfront costs associated with water and sanitation infrastructure investment remain as the key challenge, even though the price in terms of life-years saved appears rather low. On average, we find that countries would have to spend about 65-80% of their annual GDP per capita per life-year saved, which makes the provision of water and sanitation infrastructure a cost-effective intervention according to the WHO. In terms of the absolute number of child deaths preventable, the potential impact of water and sanitation technology is unlikely to be matched by any other health intervention available today as water and sanitation improvements address one of today's major causes of child mortality in developing countries – diarrhea.

Bibliography

Aiello, A., Larson, E., & Sedlak, R. (2008). Hidden heroes of the health revolution: Sanitation and Personal Hygiene. *American Journal of Infection Control , 36* (10), 128-151.

Cairncross, S. & Kolsky, P. (1997). Letter: 'Water, waste, and well-being: a multicountry study'. *American Journal of Epidemiology*, 146 (4), 359–361.

Caulfield, L.E., de Onis, M., Blössner, M. & Black, R.E. (2004). Undernutrition as an underlying cause of child deaths associated with diarrhea, pneumonia, malaria, and measles. *American Journal of Clinical Nutrition*, Vol. 80, No. 1, 193-198, July.

Clasen T., Haller, L. Walker, D., Bartram, J., & Cairncross, S. (2007). Cost-effectiveness of water quality interventions for preventing diarrheal disease in developing countries. *Journal of Water and Health* 05.4, 599-608.

Colin, D., Mathers, C.D., Lopez, A. D., & Murray C.J.L. (2001). The Burden of Disease and Mortality by Condition: Data, Methods, and Results for 2001 (Chapter 3). In: Lopez, A.D., Mathers, C.D., Ezzati, M., Jamison, D.T., Murray, C.J.L., *Global Burden of Disease and Risk Factors*. New York: Oxford University Press.

Cutler, D., & Miller, G. (2005). The Role of Public Health Improvements in Health Advances: The Twentieth-Century United States. *Demography , 42* (1), 1-22.

Deaton, A. (2006). The Great Escape: A Review of Robert Fogel's The Escape from Hunger and Premature Death, 1700-2100. *Journal of Economic Literature , XLIV*, 106-114.

Esrey, S., Potash, J., Roberts, L., & Shiff, C. (1991). Effects of Improved Water Supply and Sanitation on Ascariasis, Diarrhoea, Dracunculiasis, Hookworm Infection, Schistosomiasis, and Trachoma. *Bulletin of the World Health Organization , 69* (5).

Esrey, S. (1996). Water, Waste and Well-Being: A Multicountry Study. *American Journal of Epidemiology , 143* (6), 608-623.

Ewbank, D., & Preston, S. (1990). Personal Health Behaviour and teh Decline in Infant and Child Mortality: the United States, 1900-1930. In J. Caldwell, S. Findley, & C. P., *What We Know about Health Transition: The Culture, Social and Behavioural Determinatns of Health.* Canberra: The Australian National University Printing Service.

Fewtrell, L., & Kaufmann, R. (2005). Water Sanitation and Hygiene Intervetnions to Reduce Diarrhoea in Developed Countries: A Systematic Review and Meta-Analysis. *Lancet Infectious Diseases, 5*.

Fewtrell, L., Pruess-Uestuen, A., Bos, R., Gore, F., & Bartram J. (2007). Water, sanitation and hygiene. Quantifying the health impact at national local levels in countries with incomplete waters supply and sanitation coverage. *Environmental Burden of Disease Series*, No. 15. Geneva: World Health Organization.

Filmer, D. & Pritchett, L. (2001): Estimating Wealth Effects Without Expenditure Data – or Tears. An Application to Educational Enrollments in States of India.

Demography, Volume 38-Number 1, February 2001: 115–132

Günther, I., & Fink, G. (2010). Water, Sanitation and Children's Health. Evidence from 172 DHS Surveys. *World Bank Policy Research Working Paper*, 5275.

Heston, A., Summers, R., & Aten, B. (2009). *Penn World Table Version 6.3*. Center for International Comparisons of Production, Income and Prices at the University of Pennsylvania.

Hutton, G., & Haller, L. (2004). *Evaluation of Costs and Benefits of Water and Sanitation Improvements at the Global Level.* World Health Organization.

Hutton, G., Haller, L., & Bartram, J. (2007). Global cost-benefit analysis of water supply and sanitation intervention. *Journal of Water and Health , 05.4*, 491-502.

Knapp, A., Parkinson, J., & Schuen, R. (2009). *Study for Financial and Economic Analysis of Ecological Sanitation in Sub-Saharan Africa.* World Bank: Water and Sanitation Program-Africa.

Mathers, C.D., Salomon, J.A., Ezzati, M., Begg, S., Hoorn, S.V., & Lopez, A.D. (2001). Measuring the Global Burden of Disease and Risk Factors, 1990-2001 (Chapter 5). In: Lopez, A.D., Mathers, C.D., Ezzati, M., Jamison, D.T., Murray, C.J.L., *Global Burden of Disease and Risk Factors*. New York: Oxford University Press.

Pruess, A., Kay, D., Fewtrell, L., & Bartram, J. (2002). Estimating the Burden of Disease from Water, Sanitation, and Hygiene at a Global Level. *Environmental Health Perspectives*, 110(5), 537-542.

Pruess-Uestuen, A., Bos, R., Gore, F. & Bartram, J. (2008). *Safer Water, Better Health.* Geneva: World Health Organization.

Pruess-Uestuen, A., Bonjour, S. & Corvalan, C. (2008). The impact of the environment on health by country: a meta-synthesis. *Environmental Health,* 7: 1-10.

Rijsberman, F. R., & Zwane, A. P. (2008). *Copenhagen Consensus 2008 Perspective Paper. Sanitation and Water*. Copenhagen: Copenhagen Consensus.

Rutstein, S.O. (2000). Factors Associated with Trends in Infant and Child Mortality in Developing Countries during the 1990s. *Bulletin of the World Health Organization*, 78 (10), 1256-1270.

Szreter, S. (1988). The Importance of Soical Intervention in Britain's Mortality Decline 1850-1914. *Social History of Medicine , 1* (1), 1-37.

UN. (2009). *The Millennium Development Goals Report 2009.* New York: United Nations.

Waddington, H., Snilstveit, B., White, H., & Fewtrell, L. (2009). Water, sanitation and hygiene interventions to combat childhood diarrhoea in developing countries. *International Initiative for Impact Evaluation. Synthetic Review 001.*

WHO. (2008). World Health Organization Global Burden of Disease. 2004 Update.

WHO/UNICEF (2004). *Meeting the MDG Drinking Water and Sanitation Target. A Mid-Term Assessment of Progress*. Geneva: World Health Organization.

WHO/UNICEF. (2000) *Global Water Supply and Sanitation Assessment*. New York: World Health Organization and United Nations Children’s Fund.

Whittington, D., Hanemann, W., Sandoff, C., & Jeuland, M. (2008). *Copenhagen Consensus 2008 Challenge Paper. Sanitation and Water.* Copenhagen: Copenhagen Consensus.

Wright, J., Gundry, S., & Conroy, R. (2004). Household Drinking Water in Developing Countries: A systematic review of microbiological contamination between source and point-of-use. *Tropical Medicine and International Health , 9* (1), 106-117.

Woods, R. I., Watterson, P., & Woodward, J. (1988). The Causes of Rapid Infant Mortality Decline in England and Wales, 1861- 1921 Part I. *Population Studies , 42* (3), 343-366.

Zwane, A. P., & Kremer, M. (2007). What Works in Fighting Diarrheal Diseases in Developing Countries? A Critical Review. *The World Bank Research Observer , 22* (1).

Annex 1: Water Infrastructure and Classification

Water Code in DHS	Unimprove	Improved	Piped	Water Code in DHS	Unimprove	Improved	Piped
....dug - well unprotected	1	0	0	private well	0	1	0
....dug well - protected	0	1	0	Protected dug well	0	1	0
....piped - public	0	1	0	Protected dug well in dwelling/years/plot	0	1	0
....piped into dwelling	0	0	1	Protected dug well in yard/plot	0	1	0
....piped into yard/plot	0	0	1	Protected public dub well	0	1	0
....spring water protected	0	1	0	Protected public well	0	1	0
....spring water unprotected	1	0	0	protected public well	0	1	0
....tube well or borehole	0	1	0	protected public well/spring	0	1	0
along the road	1	0	0	protected source	0	1	0
borehole in yard/plot	0	1	0	Protected spring	0	1	0
Bottled water	1	0	0	protected spring	0	1	0
bottled water	0	1	0	protected well	0	1	0
bottled water/refilling station	0	1	0	protected well in dwelling	0	1	0
bottler water	0	1	0	protected well in someone else's yard/plot	0	1	0
Cart with small tank	1	0	0	protected well in yard	0	1	0
cart with small tank	1	0	0	protected well in yard/plot	0	1	0
communal tap	0	1	0	protected well/spring in yard/plot	0	1	0
Community stand pipe	0	1	0	protected without pump	0	1	0
covered public well	0	1	0	public borehole	0	1	0
covered well in compound/plot	0	1	0	public fountain	1	0	0
covered well/borehole in the yard	0	1	0	public open well	1	0	0
covered well/borehole, public	0	1	0	public protected well	0	1	0
Dam	1	0	0	Public tap	0	1	0
dam	1	0	0	public tap	0	1	0
deet tubewell	0	1	0	public tap/standpipe	0	1	0
developed spring	0	1	0	public water	1	0	0
Eau de pluie	1	0	0	public water piped into the household	0	0	1
Eau de surface riviere/fleuve/marigot	1	0	0	public water piped outside the household	0	1	0
Eau de surface source non-protege	1	0	0	public well	1	0	0
Eau de surface source protege	1	0	0	Puits non-protege dans parcelle	1	0	0
Eau du robinet dans le logement	0	0	1	Puits non-protege public	1	0	0
Eau du robinet dans parcelle	0	0	1	Puits protege dans parcelle	0	1	0
Eau du robinet du voisin	0	1	0	Puits protege/ forage/puits a pompe	0	1	0
forage	0	1	0	purified water	0	1	0
gravity flow water	0	0	1	Rain water	1	0	0
hand pump	0	1	0	rain water	1	0	0
improved spring	0	1	0	rainwater	1	0	0
in neighbor's land	0	1	0	rainwater collected in tank	1	0	0
inside dwelling	0	0	1	river	1	0	0
inside neighbor's house	0	1	0	river, stream	1	0	0
inside the house	0	0	1	river/ stream	1	0	0
naighbor's tap	0	1	0	river/dam/lake/ponds/stream/canal	1	0	0
neighbor's borehole	0	1	0	river/dam/lake/ponds/stream/canal	1	0	0
neighbor's open well	1	0	0	river/lake	1	0	0
non protected spring	1	0	0	River/stream	1	0	0
non protected well	1	0	0	river/stream	1	0	0
of a neighbor	0	1	0	river/stream not protected	1	0	0
open dug well	1	0	0	River/stream/pond/lake	1	0	0
Open public well	1	0	0	river/stream/pond/lake/dam	1	0	0
open public well	1	0	0	river/stream/spring	1	0	0
open well	1	0	0	satchel water	0	1	0
open well at neighbour	1	0	0	shallow tubewell	1	0	0
open well in compound/plot	1	0	0	Spring	1	0	0

open well in dwelling	1	0	0	spring	1	0	0
Open well in dwelling/yard	1	0	0	spring, not improved	1	0	0
open well in yard	1	0	0	stone tap/dhara	0	0	1
Open well in yard/plot	1	0	0	Surface water	1	0	0
open well in yard/plot	1	0	0	surface water	1	0	0
open well water	1	0	0	surface water (river, dam, lake, stream...)	1	0	0
open well with sump pump	0	1	0	surface water (river/dam)	1	0	0
open well without sump pump	1	0	0	surface water, spring, river, stream	1	0	0
other rainwater	1	0	0	surface well/other well	1	0	0
piped outside dwelling	0	1	0	Tanker truck	1	0	0
Piped â€“ public tab	0	1	0	tanker truck	1	0	0
Piped in dwelling	0	0	1	Tanker truck/bowser	1	0	0
Piped in dwelling/years/plot	0	0	1	tanker truck/peddler	1	0	0
piped in own land	0	0	1	Tanker truck/water vendor	1	0	0
piped in the courtyard	0	0	1	traditional public well	1	0	0
piped in the house	0	0	1	traditional well in the yard	1	0	0
piped inside dwelling	0	0	1	Tube well or borehole	0	1	0
piped into compound/plot	0	0	1	tube well or borehole	0	1	0
Piped into dwelling	0	0	1	Tubed/piped well or bore hold in yard	0	1	0
piped into dwelling	0	0	1	tubewell	0	1	0
piped into plot/yard	0	0	1	undeveloped spring	1	0	0
piped into residence/yard	0	0	1	Unprotected dug well	1	0	0
piped into residence/yard/plot	0	0	1	unprotected public well	1	0	0
piped into someone else's yard/plot	0	1	0	unprotected public well/spring	1	0	0
Piped into tap in yard/plot	0	0	1	Unprotected spring	1	0	0
piped into yard/lot	0	0	1	unprotected spring	1	0	0
Piped into yard/plot	0	0	1	unprotected well	1	0	0
piped into yard/plot	0	0	1	unprotected well/spring in yard/plot	1	0	0
piped into yard/plot/building	0	0	1	vendor = cart with small tank	1	0	0
piped into yard/spot	0	0	1	water from well	1	0	0
piped outside dwelling	0	1	0	water in drums/big cans	0	1	0
piped to neighbour	0	1	0	water merchant from covered well	0	1	0
piped to yard/plot	0	0	1	water merchant from pond/lake	1	0	0
piped water from rural system	0	1	0	water merchant from traditional well	1	0	0
piped water from utility company	0	1	0	water merchant from unknown source	1	0	0
pond, lake	1	0	0	water sale by company	0	1	0
pond/ lake	1	0	0	water vendor	1	0	0
Pond/lake	1	0	0	well into dwelling/yard/plot	1	0	0
pond/lake	1	0	0	well water with pump	0	1	0
pond/lake/dam	1	0	0	well water with winch	0	1	0
pond/tank/lake	1	0	0	well with electrical pump	0	1	0
private water piped into the house	0	0	1	well with pump	0	1	0
private water piped outside the house	0	1	0	well without electrical pump	1	0	0

Annex 2: Sanitation Infrastructure and Classification

Toilet Code in DHS	Open	Improved	Flush	Toilet Code in DHS	Open	Improved	Flush
....flush - to septic tank	0	0	1	no facility	1	0	0
....flush - don't know	0	1	0	no facility, bush, field	1	0	0
....flush - to piped sewer system	0	0	1	no facility, bush, field	1	0	0
....flush - to pit latrine	0	1	0	no facility/ bush/ field	1	0	0
....not facility	1	0	0	No facility/bush/field	1	0	0
....pit latrine - ventilated improved	0	1	0	no facility/bush/field	1	0	0
....pit latrine - with slab	0	1	0	no facility/field	1	0	0
....pit latrine - without slab	1	0	0	no facility/uses bush/field	1	0	0
bucket	1	0	0	no flush toilet	1	0	0
bucket toilet	1	0	0	no toilet facility	1	0	0
bucket, pan	1	0	0	no toilet, in nature	1	0	0
bush	1	0	0	no toilet/bush	1	0	0
bush/field	1	0	0	no toilet/field/bush	1	0	0
bush/field (abonera)	1	0	0	non-ventilated pit latrine	0	1	0
bush/forest/yard/field/no facility	1	0	0	non-vip pit latrine with slab	0	1	0
camara septica	0	0	1	non-vip pit latrine without slab	1	0	0
CHASSE BRANCHE D’EAU	0	0	1	open latrine	1	0	0
CHASSE BRANCHE D’EAU	0	0	1	open pit	1	0	0
close pit	0	1	0	ordinary pit latrine	1	0	0
composting toilet	0	1	0	own flush toilet outsite/yard	0	0	1
composting toilet/arbo loo	0	1	0	own flush toilet into residence	0	0	1
covered latrine	0	1	0	own pit toilet/latrine	0	1	0
covered pit latrine, no slab	1	0	0	Pas de toilette, nature	1	0	0
covered pit latrine, with slab	0	1	0	pit	1	0	0
drop/overhang	1	0	0	pit latrine	0	1	0
dry toilet	0	1	0	pit latrine - ventilated improved pit (vip)	0	1	0
field	1	0	0	pit latrine - with slab	0	1	0
flush - don't know where	0	1	0	pit latrine - without slab / open pit	1	0	0
flush - to piped sewer system	0	0	1	pit latrine - without slab/open pit	1	0	0
flush - to pit latrine	0	1	0	pit latrine with drainage	0	1	0
flush - to septic tank	0	0	1	pit latrine with slab	0	1	0
flush - to somewhere else	0	1	0	pit latrine without slab	1	0	0
flush connected to sewer/with septic	0	0	1	pit latrine without slab/open pit	1	0	0
flush or pour flush toilet	0	0	1	pit toilet	0	1	0
flush other	0	1	0	pit toilet with basinet (private)	0	1	0
flush to elsewhere	0	1	0	pit toilet with bassinet (shared)	0	1	0
flush to latrine	0	1	0	pit toilet without bassinet (private)	1	0	0
flush to piper sewer	0	0	1	pit toilet without bassinet (shared)	1	0	0
flush to pit latrine	0	1	0	private flush toilet	0	0	1
flush to septic tank	0	0	1	private with no septic tank	0	1	0
flush to sewer system	0	0	1	private with septic tank	0	0	1
flush to somewhere else	0	1	0	public toilet	0	1	0
flush toileet	0	0	1	river	1	0	0
Flush toilet	0	0	1	river/canal	1	0	0
flush toilet	0	0	1	river/stream/creek	1	0	0
flush toilet (rain water sewer)	0	1	0	rudimentary pit toilet latrine	1	0	0
flush toilet (rivers)	0	1	0	septic tank/modern toilet	0	0	1
flush toilet (sewer)	0	0	1	share flush toilet into residence	0	0	1
flush toilet (sink-sumidero)	0	0	1	share flush toilet outside/yard	0	1	0
flush toilet connected to a septic tank	0	0	1	share pit toilet/letrine	0	1	0
flush toilet connected to sewer	0	0	1	shared flush toilet	0	1	0
flush toilet does not know connection	0	1	0	shared/public	0	1	0
flush toilet not connected to sewer	0	1	0	toilet connected to plot/yard	0	0	1

flush toilet private	0	0	1	toilet connected to septic well	0	0	1
flush toilet shared	0	1	0	toilet connected to sewer	0	0	1
flush toilet: own	0	0	1	toilet inside	0	0	1
flush toilet: shared	0	1	0	toilet outside	0	1	0
flush unconnected to sewer/without	0	1	0	toilet with connection to open water	1	0	0
flush, don't know where	0	1	0	traditional pip toilet	1	0	0
flushed to piped sewer system	0	0	1	traditional pit latrine	1	0	0
flust toilet (septic tank)	0	0	1	Traditional pit toilet	1	0	0
flust, don't know where	0	1	0	traditional pit toilet	1	0	0
Fosse/latrines ameliores	0	1	0	traditional pit/latrine unconnected to	0	1	0
Fosse/latrines rudimentaires	1	0	0	traditional toilet to sea/river (low tide)	1	0	0
hanging latrine	1	0	0	uncovered pit latrine, no slab	1	0	0
hanging letrine (colgante)	1	0	0	uncovered pit latrine, with slab	1	0	0
hanging toilet	1	0	0	ventilated improved latrine	0	1	0
hanging toilet/ hanging letrine	1	0	0	ventilated improved pit (vip) latrine	0	1	0
hanging toilet/latrine	1	0	0	ventilated improved pit (vip) latrines	0	1	0
improved pit latrine	0	1	0	ventilated improved pit lat	0	1	0
improved pit toilet latrine	0	1	0	Ventilated improved pit latrine	0	1	0
latrine	0	1	0	ventilated improved pit latrine	0	1	0
latrine connected to septic tank	0	1	0	ventilated improved pit toilet	0	1	0
latrine with composting facility	0	1	0	ventilated improved pit/latrine	0	1	0
latrine with connection to open water	1	0	0	ventilated improved privy	0	1	0
latrine with siphon	0	1	0	ventilated pit latrine	0	1	0
latrines	0	1	0	vip	0	1	0
modern flush toilets	0	0	1	vip latrine	0	1	0
				water sealed/slab latrine	0	1	0